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A MODEL TO PREDICT HUMAN SKIN BURNS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A model to predict burns to human skin is discussed. The model utilizes a finite difference heat transfer technique to predict skin temperatures. The wavelength-dependent absorptance of the skin is considered. First and second degree burns are predicted, based on an experimentally-derived time-temperature relationship.

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I. INTRODUCTION

The use of fire as a weapon by man precedes recorded history.
Anthropologists theorize that early man used burning brush to scare
wild animals from his habitat. More recently, the ancient Romans and
Greeks used firebrands and boiling oil or water to repel invaders.
During the early twentieth century, many incendiary and pyrotechnic
munitions were developed. Three decades ago, the world was introduced
to the atomic bomb and its sun-like fireball. Given the resourceful-
ness of man and the knowledge of modern science, the "ray gun" may be-
come reality.

All of these weapons have the same basic purpose: the incapacitation
and/or death of the enemy by pain and burning. In the past, weapons
were fabricated out of locally available materials that were obtained
at minimal cost. Because the monetary investment was so low, a trial-
and-error approach was used in developing such new weapons as were re-
quired. During the past fifty years, however, weapons and weapons
systems have become both complex and expensive. Because of this, man
has turned to science both to develop the weapons and to guarantee
their effectiveness when developed. The most expeditious method of
determining a weapon's effectiveness is to test a prototype model against
the intended target. However, the intended target in these cases is
man and the indiscriminate burning of humans is proscribed by most
cultures. There exist several alternatives: testing on human volunteers
under carefully controlled conditions, testing on human surrogates
(animals), and mathematical simulation. The first alternative is used
to some extent, however, the temperature range over which testing is
done is limited by the reluctance of the volunteers to undergo permanent
bodily damage. The use of animals, a general practice, suffers from
several disadvantages: (1) the physiology of the animal is not identical
to that of the human, (2) animals are expensive to buy, feed, and house,
and (3) the administrative procedures required to gain approval for
animal experiments are formidable. The last alternative, mathematical
simulation, has been used to a limited extent during the past two dec-
ades. The equations developed were strictly empirical relationships
that attempted to predict subcutaneous skin temperatures on the basis
of incident irradiance. Because of the complexity of the subject, many
simplifying assumptions were made. The model described in this report
views the subject as a simple heat transfer problem amenable to analysis
by theoretical means.

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II. MODELING TECHNIQUES

In order to model any system successfully, it is necessary to establish a relationship between the response of the system and one or more parameters that can be determined either empirically or theoretically. Thus, the question to be answered for this model was "Is there a relationship between skin temperatures and skin burns?". This question was answered by Hardy[1] who made extensive experimental observations of burn thresholds as a function of skin temperature. In order to calculate skin temperatures, however, a knowledge of the thermophysical properties of the skin and underlying tissue is needed. NASA[2], as part of the space program, has compiled extensive data on human responses to the aerospace environment. The needed thermophysical data was found in these volumes.

Figure 1 presents a cross sectional view of a portion of the volume of flesh described by this model. The skin varies from 0.5mm on the eyelids to 5.0mm on the back. Since the tissue underlying the skin serves as either a heat source or a heat sink, a volume 2.5cm in depth has been modeled. The epidermis, which is approximately 300μm thick, is avascular and does not significantly affect the occurrence of first and second degree burns. Therefore, the temperature of the outermost layer of the dermis at a depth of 500μm was selected as the basis for the burn criteria.

The burn criteria, taken from Hardy, are shown in Figure 2. The area to the upper right of the solid line denotes irreversible tissue damage,i.e., a second degree burn; the area between the dashed and solid lines denotes transient erythema, i.e., a first degree burn. Histologically, a first degree burn is characterized by immediate pain, which continues after exposure and by ensuing redness (caused by dilation of arterioles) in the exposed area which disappears in about 24 hours. The first degree burn is said to be reversible tissue injury. The second degree burn is characterized by pain with either no visible effect or by an immediate appearance of blanching, loss of elasticity, swelling or blisters. After 6 to 24 hours, an eschar forms over the injured area and is flexible and tan or brown if the injury is light, or thick, stiff and dark if the injury is severe. A second degree burn does not involve the full thickness of the skin and the remaining cells are able to regenerate a normal skin. A third degree burn is defined as the destruction of the full skin thickness. All of the cells are destroyed and are unable to regenerate a normal skin.

A finite difference technique has been employed in this model to perform the heat transfer calculations. These techniques are particularly suited to problems involving complex geometries and boundary conditions, nonlinearities such as radiation, and variable material properties. The reader interested in additional information on finite differencing
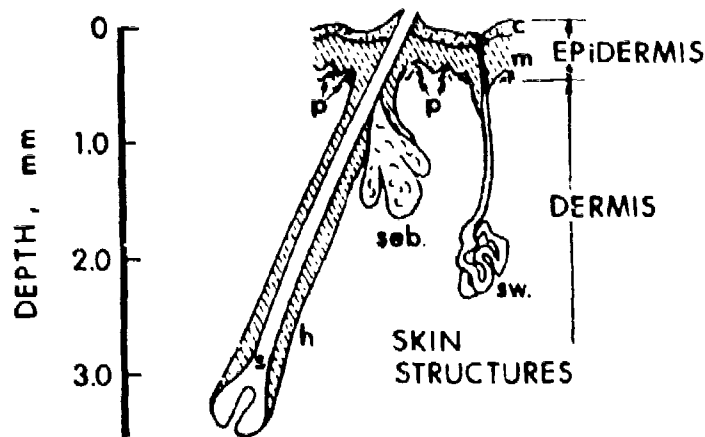
LEGEND:

c = CORNEUM   s = HAIR SHAFT

h = HAIR FOLLICLE   seb = SEBACEOUS GLAND

m = MALPIGHIAN LAYER   sw = SWEAT GLAND

p = THE MOST SUPERFICIAL BLOOD VESSELS, ARTERIOLES,
      CAPILLARIES AND VENULES.
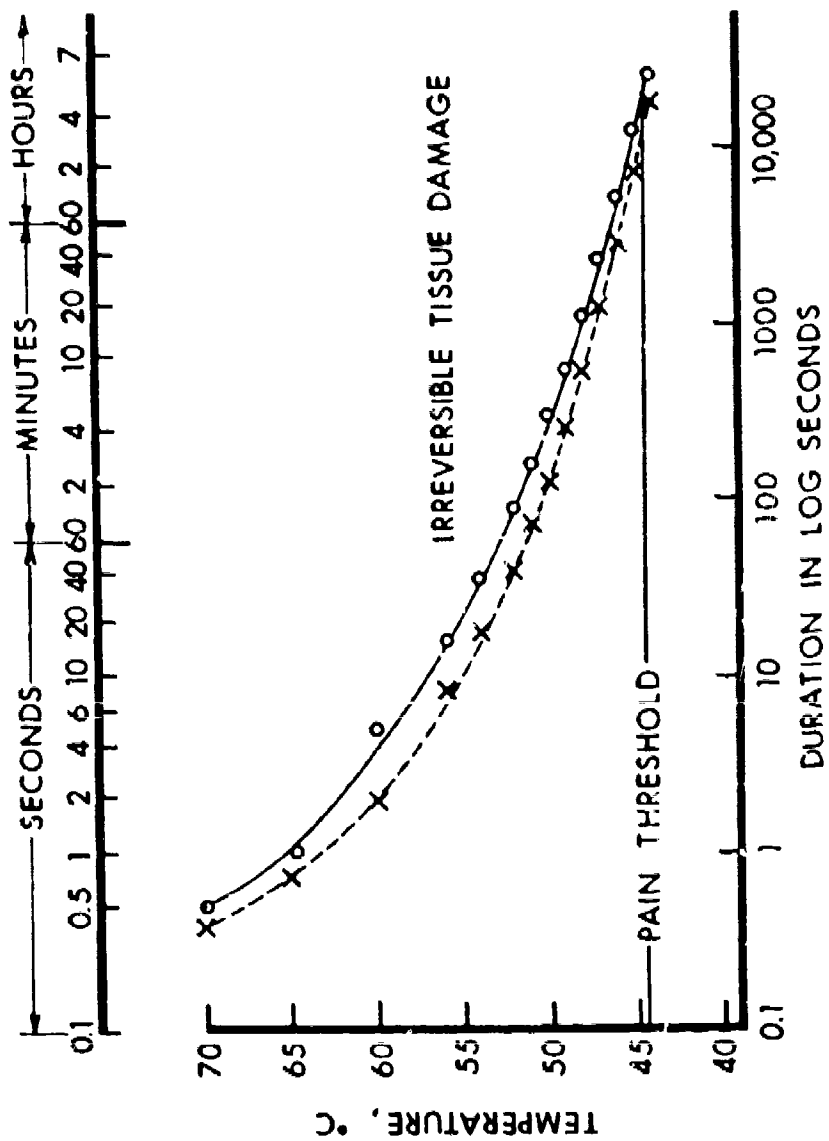
Figure 1.   Cross Section of Human Skin

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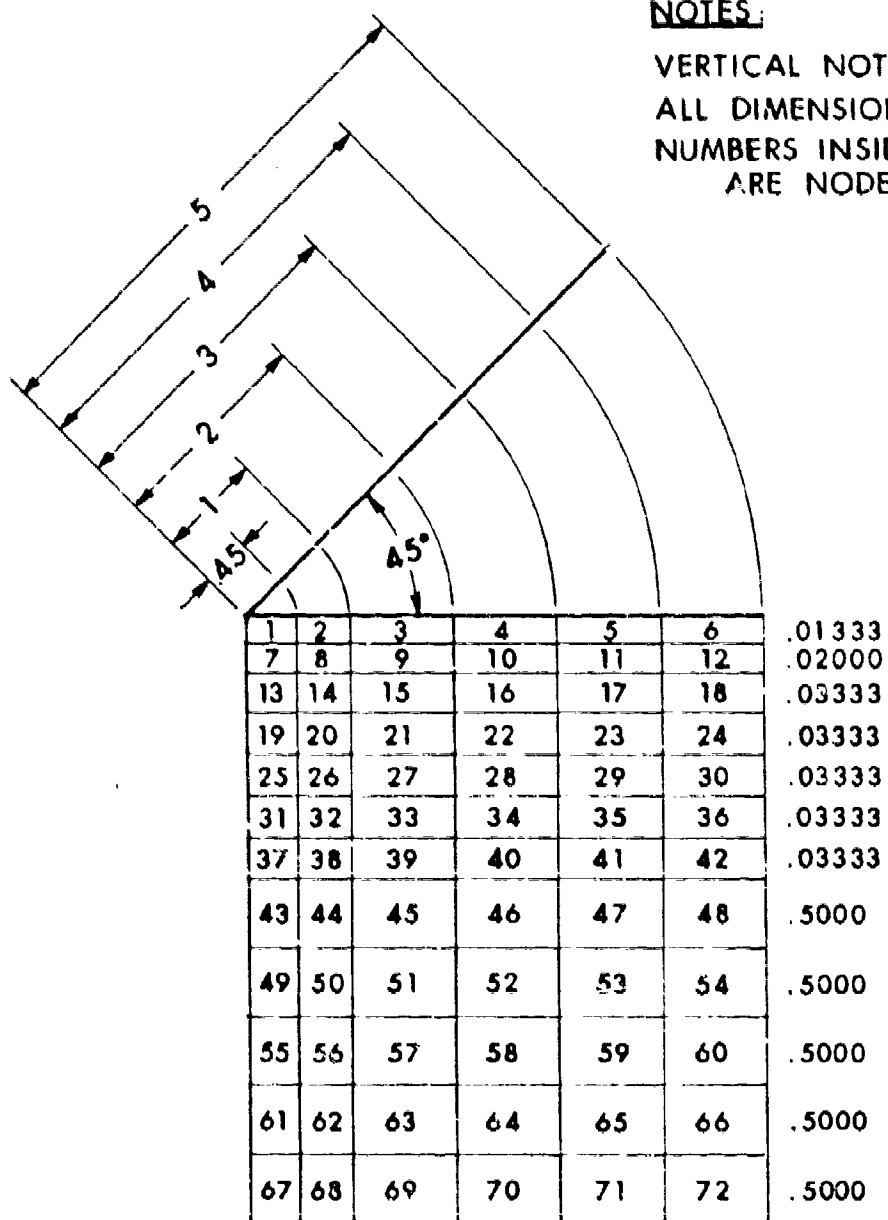Figure 2. Burn Criteria for Human Skin

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is referred to either Gaski[3] or Meyers[4]. The tissue to be modeled was subdivided into the 72 small volumes shown in Figure 3. Each volume is assumed to have uniform thermophysical properties and temperatures throughout. For computer purposes, a nodal point, located in the geometric center of the volume, is assigned these properties. To effect heat transfer, mathematical conductors are constructed to connect these nodes. They are assigned the heat conduction properties of the media which they represent. The skin density (1.1 g/cm^3) and heat capacity (0.8 cal/g-°c) are taken from Reference 3. The thermal conductivity data shown in Figure 4 was taken from Weaver[5].

At this point it is appropriate to discuss energy flow through the model. There are two separate sources of thermal energy acting upon the skin: the outward flow of heat from the interior of the body and the inward flow of heat from external sources incident upon the skin surface. The first source is fairly simple to model since the rates of heat loss for various bodily areas are known from aerospace cooling studies[6]. The method used in this case is to input the energy into the innermost nodes and let the model transport it to the surface where it is dissipated via convection and radiation. The second source is more complex since external heat sources can be of three types: radiative, convective and conductive. Of these, only radiative sources have been considered to date. Subroutines have been written to generate the following pulse shapes: square, delta, nuclear, and laser. An additional subroutine allows the user to input an arbitrary pulse shape.

Radiant sources have a spectral emittance that depends upon the temperature of the source and whether the source emits as a blackbody or a gray surface. This spectral distribution is important because the absorptance of radiant thermal energy by human skin is a function of photon energy. Subroutines are included that correct for this energy dependence provided that: (a) a blackbody temperature is known, (b) the source spectrum is known, (c) the overall skin absorptance is known, or (d) in the case of lasers, the emitted wavelength is known. If none of the preceding are known, a worst-case approach is taken where all energy is assumed to be absorbed. Gray surface emission and atmospheric attenuation are not considered by the model.

III. MODEL VERIFICATION AND APPLICATION

To date only a minimum of model verifications has been performed. This is not considered critical at this time for the following reasons: (1) the model is still under development, (2) the finite-difference technique used has been well proven, and (3) adjustment of constants to correct for minor inaccuracies is particularly easy in this model. One verification attempt has been made and is shown in Figure 5. The peak calculated temperature varied from the peak experimental temperature by only 2%. It is felt that any agreement better than this would be fortuitous.

1	2	3	4	5	6	.01333
7	8	9	10	11	12	.02000
13	14	15	16	17	18	.03333
19	20	21	22	23	24	.03333
25	26	27	28	29	30	.03333
31	32	33	34	35	36	.03333
37	38	39	40	41	42	.03333
43	44	45	46	47	48	.5000
49	50	51	52	53	54	.5000
55	56	57	58	59	60	.5000
61	62	63	64	65	66	.5000
67	68	69	70	71	72	.5000

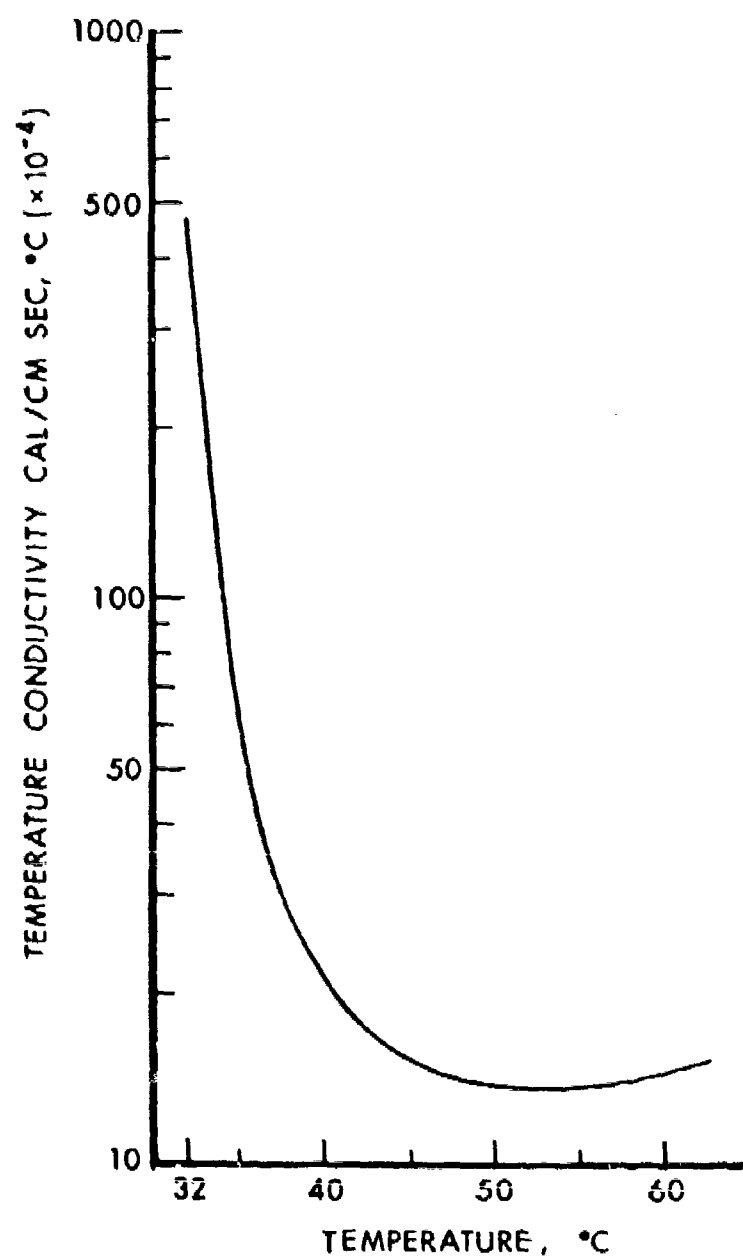Figure 3. Nodal Model for Skin Burn Calculations.
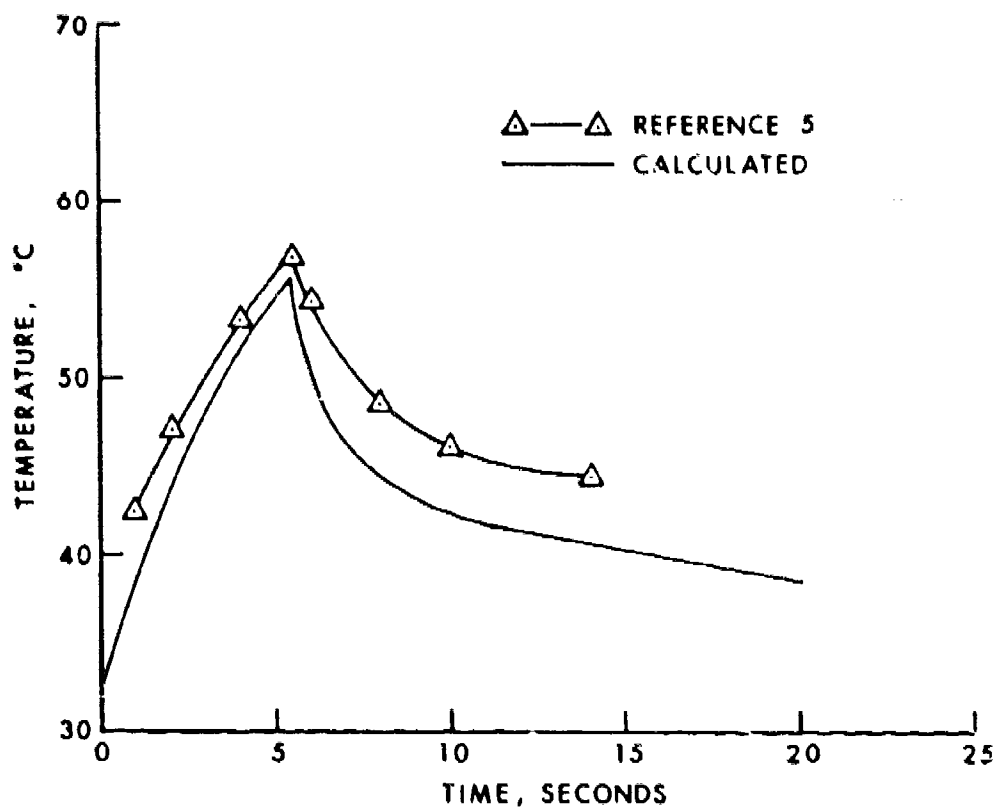
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Figure 4. Thermal Conductivity Data

Figure 5. Calculated and Experimental
Temperature Histories.

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Upon completion of the model, additional verifications will be performed using data from carefully controlled experiments.

Future work on the model will include the coding of conductive and convective heat source routines to permit the evaluation of pyrotechnic and incendiary weapons that burn by either direct contact or by the heating of the ambient air.

Because man is the controlling factor in the vulnerability assessment of many Army systems, it seems logical that the next step after this model would be a vulnerability code that would predict the degree of incapacitation of man, using data generated by this model.

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